FASTC-ID(RS)T-0735-92

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TOWARD THE WING VORTEX BREAKDOWN

by

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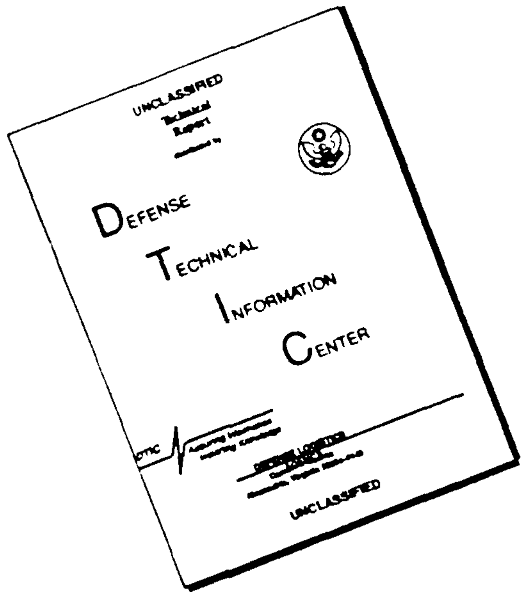

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FASTC-ID(RS)T-0735-92 16 July 1993

MICROFICHE NR: 93C000456

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English pages: 9

Source: Hangkong Xuebao, Vol. 11, Nr. 12, 1990; pp. 588-591

Country of origin: China
Translated by: SCITRAN
F33657-84-D-0165
Requester: FASTC/TATV/Paul F. Freisthler
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The Effect of the Nose Shape and Wing Location Toward the Wing Vortex Breakdown

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Abstract The variation of the wing vortex breakdown vs. the angle of attack for a missile with a cruciform set of wings was investigated through experiments. The tests were carried out by conducting the flow pattern visualization in the water channel at BUAA. The model had two nose shapes - pointed and blunted nose. The wing was set at fore or aft location along the axis of the body. The experimental results indicate that for the configuration with the same nose, the location of the vortex breakdown for the wing with aft location is closer to the wing trailing edge than that of the wing with fore location. While for the configuration with wing at aft location, the wing vortex breakdown for the blunt nose is delayed comparing to that for the pointed nose.

Key words: wing-body combination, separation flow, vortex breakdown

(Manuscript received on December 4, 1989. Revised version received on May 20, 1990.)

I. Introduction

In order to obtain highly dynamic characteristics, modern fighter planes and tactical guided missiles fly at big attack angles. It is well known that the breakdown of wing vortex has important effect on the dynamics of tactical guided missiles flying at big angles. Therefore, the factors influencing vortex breakdown are major emphasis for the design departments. Experimental study and engineering calculation of vortex breakdown for single wing at the fore location have been reported,[1-4] while the vortex breakdown for multiple wing configurations has not been studied extensively. References 5 and 6 pointed out the effect of wing surface on missile body vortex but the effect on the wing vortex was not included. In this paper, the emphasis was placed on the factors influencing wing vortex breakdown and the effect of nose shape and wing location of cruciform wing configuration on wing vortex breakdown.

2. Experimental Model and Set-Up

The experiment was carried out in the water tank of fluid dynamics institute of Beijing University of Aeronautics and Astronautics. The experiment section of the water tank was 6.8m long, with a cross section of $0.4 \times 0.4 m^2$. Water flow speed was between 0.1 and 0.7m/s and the Re number was 2×10^3 (missile body diameter was the reference dimension). The experimental model was a cruciform wing-body configuration (see figure 1). There were two nose shapes: pointed-head parabolic spiral form and blunted-

head elliptic spiral form and two dimensionless distances from the tip of the wing edge to the apex of missile nose: 0.41 and 0.6. Manifestation of the flow pattern was achieved through dye method and the outlet of the dye was positioned at the two sides of the nose and the leading edge at the root of the wing, hole diameter was 1mm. Flow rate of the dye was controlled by changing the height of the dye container to ensure that no injection flow should form when the dye flowed out so that actual situation could be modeled. Since the wing vortex breakdown was non-regular flow and the locations for left and right vortex breakdown were usually asymmetrical, the locations for vortex breakdown reported in this paper were time-averaged values, and an average was taken when the left and right vortex breakdown locations were not symmetrical. Even though flow states recorded on photographs were for various instantaneous moment, the photographs shown in this paper were close to the time-average value and should be regarded as time-average flow state.

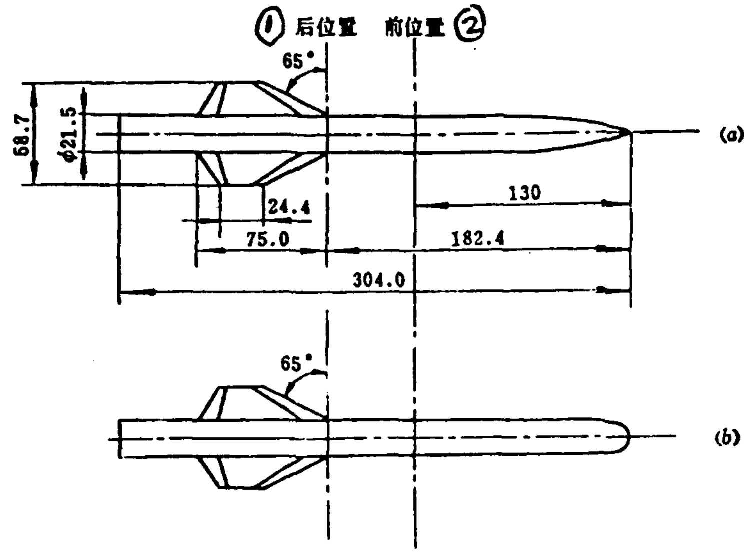

Figure 1: Model dimension

Key: 1 - aft location, 2 - fore location

3. Results and Discussion

After repeated observation and recording, the variation of wing vortex breakdown $\bar{x}_b=x_b/c_r$ with respect to attack angle α for four conditions (pointed nose: fore and aft locations, blunted nose: fore and aft locations) was shown in figure 2, where x_b was calculated from the back edge of the wing and c_r was the length of the root chord. Using the case of pointed nose, fore location as an example, the limits of the wing vortex breakdown locations were indicated by arrowheads (including the asymmetrical vortex condition) while the other three cases were only expressed in terms of the time-averaging values. From this figure, it can be known that whether the missile is pointed nose or blunted nose, the vortex breakdown point for the aft location is always farther

back than that of the fore location. This is especially clear when α<40 degrees (not as clear when α is greater than 40 degrees).

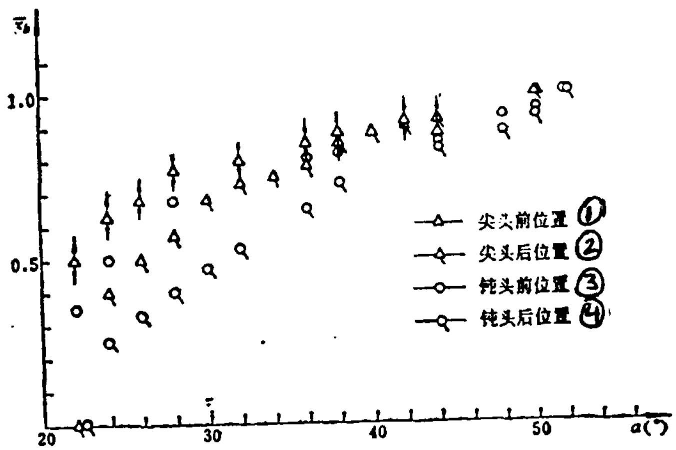

Figure 2: Variation of location of wing vortex breakdown with angle of attack

Key: 1 - pointed head, fore location; 3 - pointed head, aft location; 4 - blunt head, fore location; 5 - blunt head, aft *location*

Figure 3 shows the overview photographs of the flow state for pointed nose and fore and aft locations when α=26 degrees. Because the body vortex is composed of the separation flow of the boundary layer of the two sides of the missile wing and the wings are located on the two sides of the missile body, the boundary layer separation flow is blocked by the wing and can not be transferred to the body vortex. When the wings are located at the aft location the body vortex can develop fully and the dimension and strength of the vortex are both greater than those of the fore position. Beneficial interference on the wing vortex can be

exerted by the body vortex. As stated in reference 5: "The separation flow at the sides of the missile body after the wing aft has no contribution to the concentrated body vortex.". This was also verified in this study. In reference 7, stress test on the three combination bodies (with triangular wing shape) with identical spiral base lines but different dimensions was carried out. The result showed that when α was less than 15 degrees the normal stress of the three combination bodies was basically the same while when α was between 15 and 27 degrees the normal stress was greater if the fore body was longer. The experiment carried out in this study clarified the mechanism of this phenomenon (a longer fore body can promote the breakdown of wing vortex)

Figure 3: Look-down pictures of flow pattern of α=26 degrees pointed head configuration bodies, (a) wing aft location, (b) wing fore location.

When the missile is blunted nosed, the difference between the wing vortex breakdown point is greater for wing fore and aft locations (see figure 2). This was probably due to the models

used in this study where the fore body was longer for blunt nosed body than the point nosed body and the separation flow transferred to body vortex was greater. From the photographs in figure 4, when α was 38 degrees body vortex breakdown point was farther back from the missile aft location. When α was 44 degrees, the breakdown point was at 1/4 location before the aft location. When α was greater than 40 degrees, body vortex for single missile body broke down before the aft location and body stability was decreased and the beneficial interference with the wing vortex was also decreased. Therefore, when α was greater than 40 degrees the wing back-shift gain was not evident.

Figure 4: Side-view pictures of single-body (pointed head) flow patterns. (a) $\alpha = 38°$; (b) $\alpha = 44°$

From the experiment (figure 2) it was clear that blunted nose body had beneficial effect on the wing vortex breakdown. However, blunted nose body was also more significantly affected by Re number, therefore, it was possible the conclusion obtained in this experiment was due to the low Re number used in this

experiment. Wind tunnel surface oil flow test was carried out on the blunted nose body combination (experiment Re number was 1.2×10^5). The result showed that the initial angle of vortex breakdown (angle at breakdown point at wing back edge) based on wind tunnel test was about 1 to 2 degrees higher than the similar water tunnel test data. Reference 8 had carried out the wind and water tunnel test on the body combination of a certain type of fighter plane and the experiment Re numbers were 1.25×10^4 and 2.5×10^3. Photographs of flow state of wind and water tunnel tests at various moments were shown in that reference. From these photographs the non-regular effect of vortex breakdown point was even greater than the effect of Re numbers. Therefore, the experimental results of this study was qualitatively credible.

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